Multichannel SQUID systems

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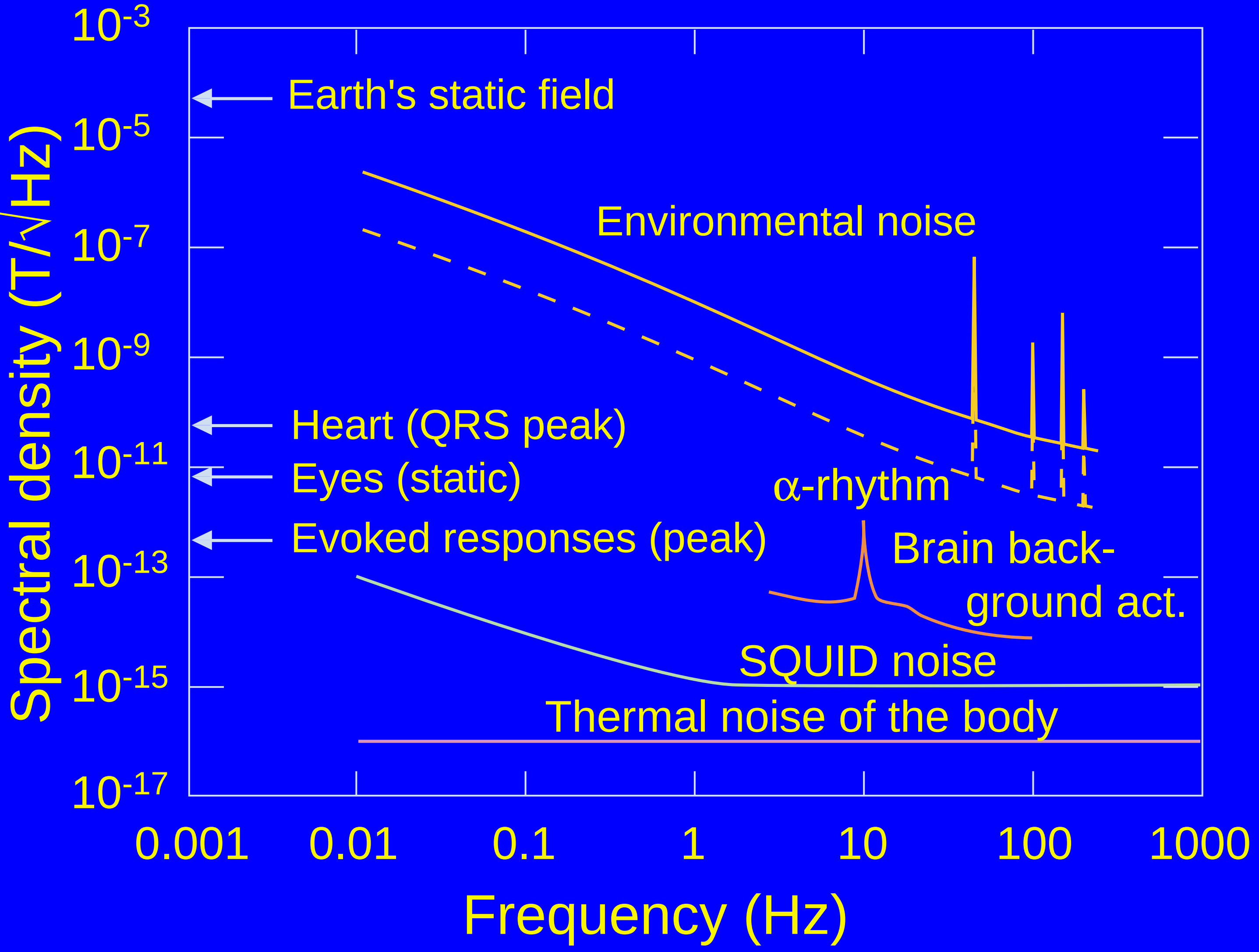
4·D | NEURO**IMAGING**

Overview of lecture

1. Overview
2. Signals and noise
3. Sensor basics
4. Magnetic shielding and noise reduction
5. Multichannel systems
6. Example

Signals and noise

Signal and noise sources



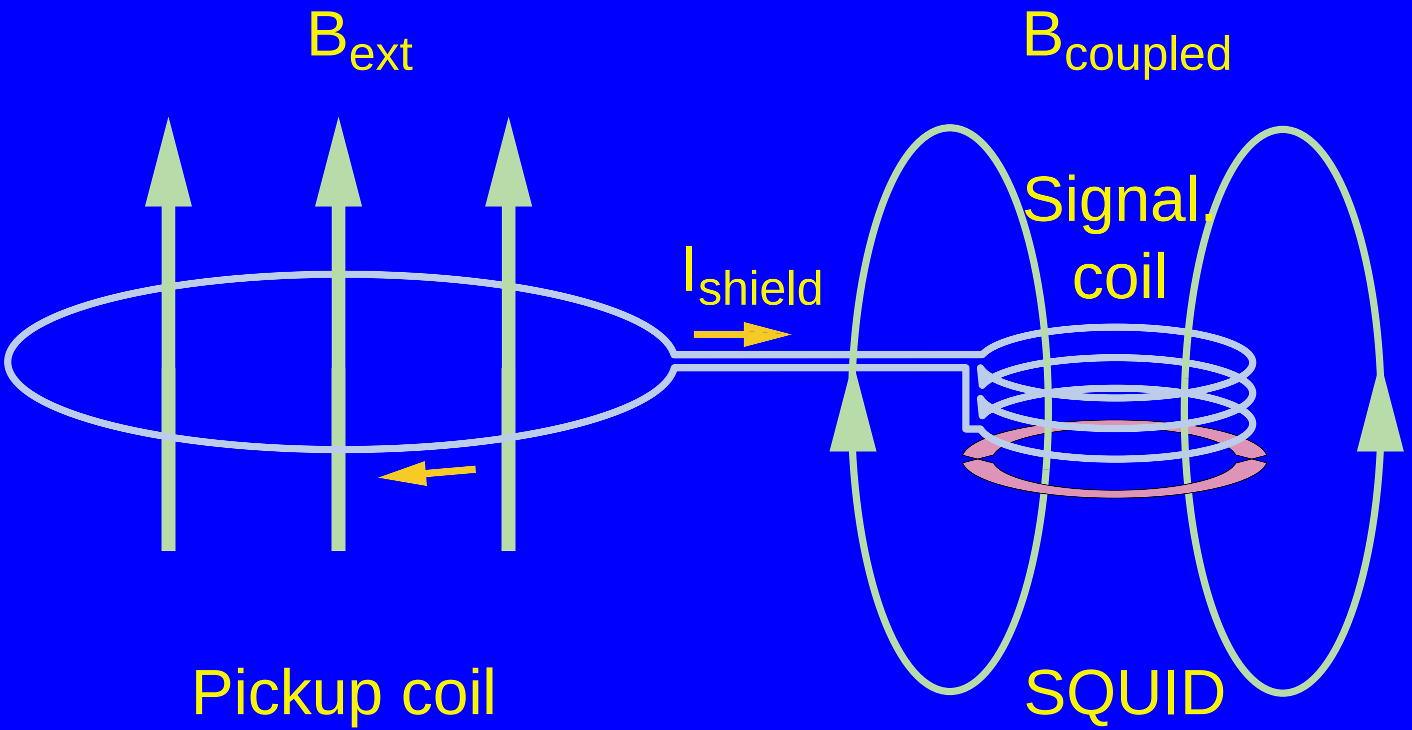
How to discern the signal ?

- Sensitivity
  - Superconducting QUantum Interference Device
- Shielding
  - Magnetically shielded rooms
- Selectivity
  - Selective pickup
  - Noise reduction after pickup

Sensor basics

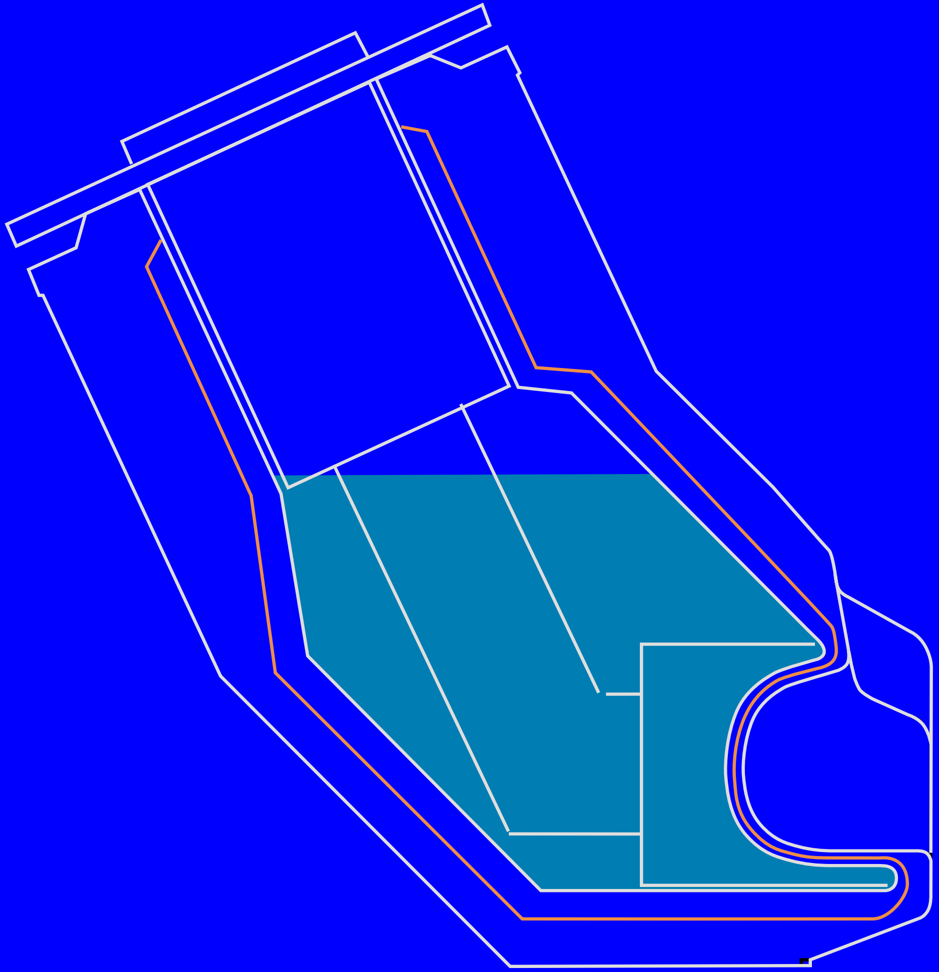
Principle of the detector

- Flux transformer
- SQUID: Flux-to-voltage transducer



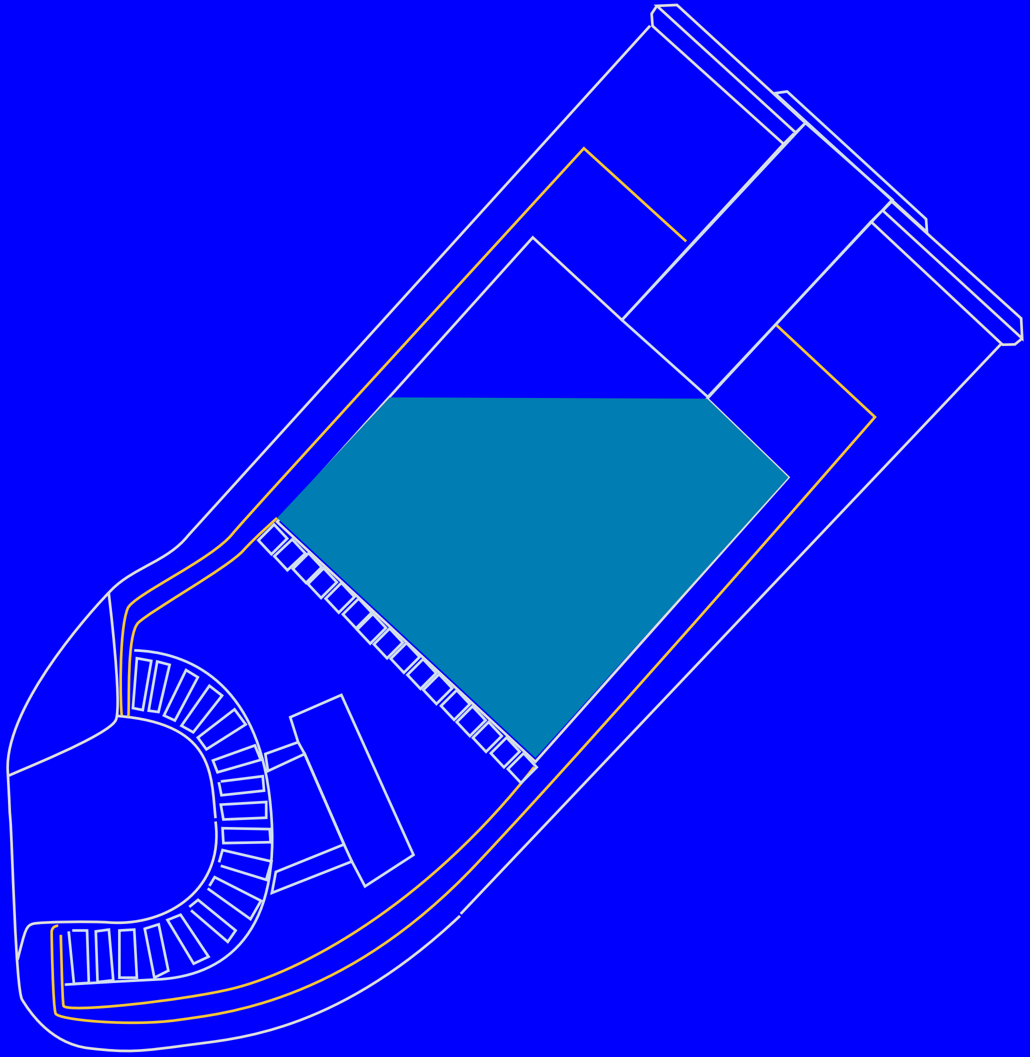
Cooling methods

- Direct immersion in liquid Helium
- Dewar



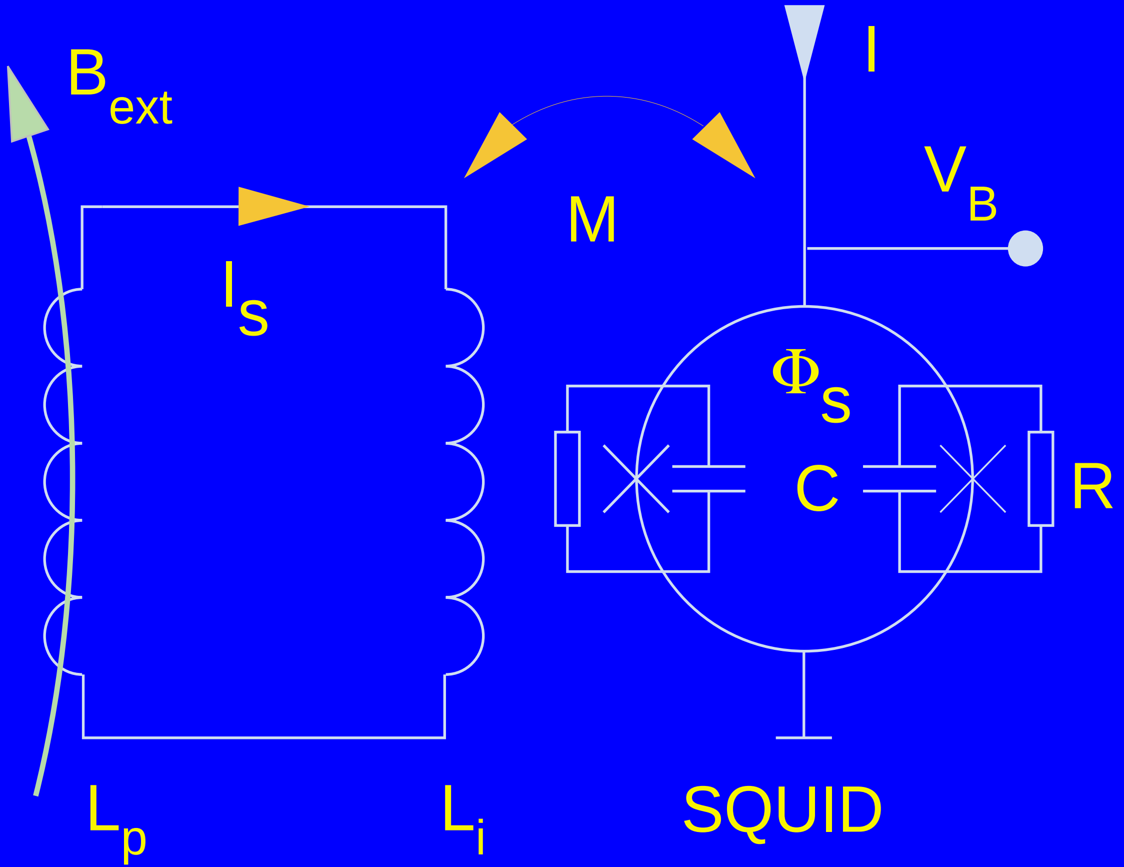
Cooling methods

- Coils in vacuum
    - Conductive cooling
- Cryocooler

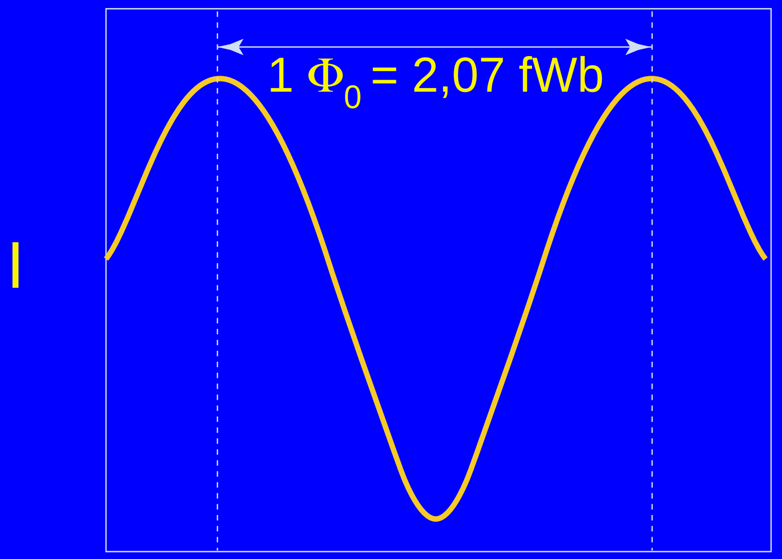


SQUID

- dc SQUID almost exclusively used



V_B = const.



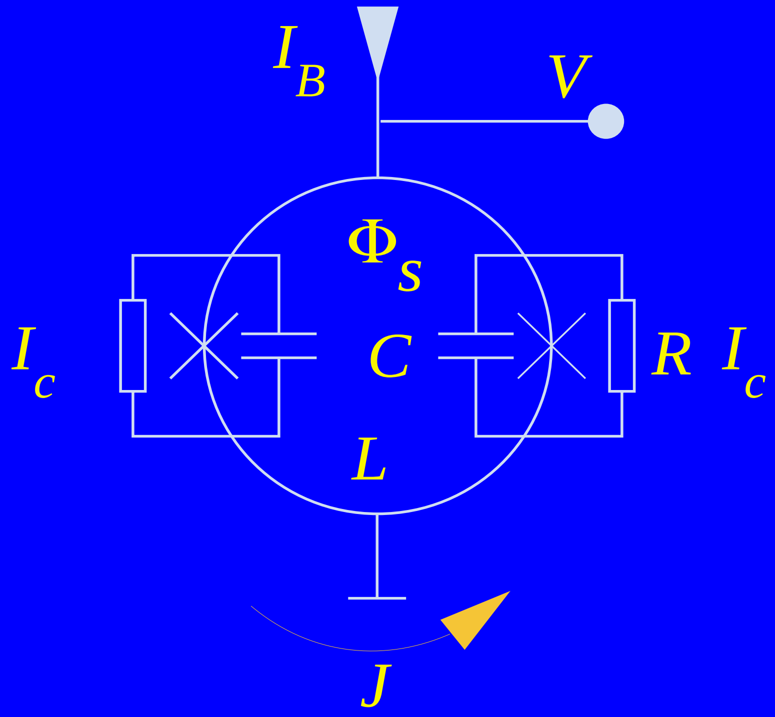
$\Phi_S = MI_S$

Sensitivity of dc SQUID

- Resistively shunted junction model
- Optimized energy sensitivity

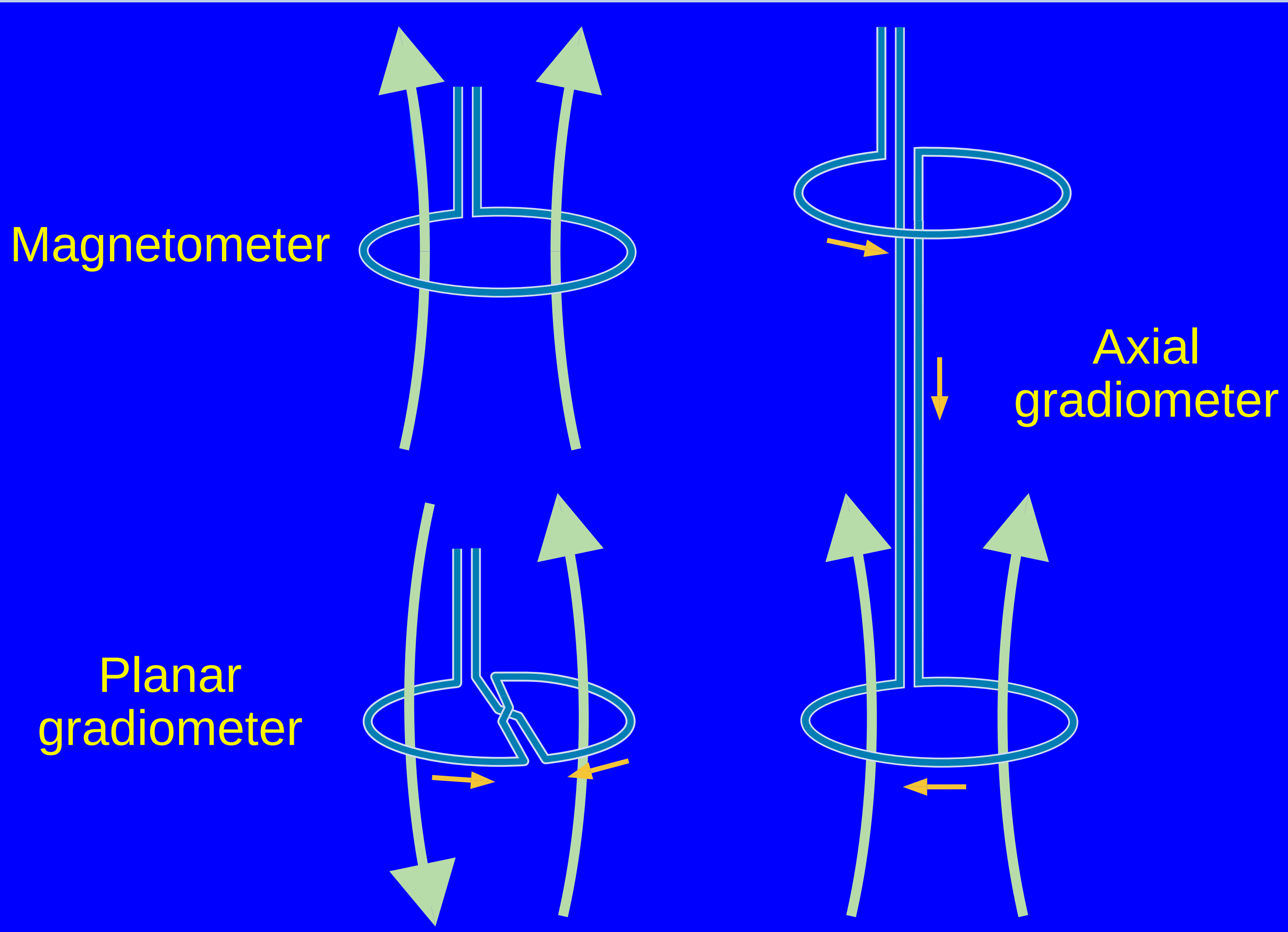
$$\varepsilon = 12\gamma k_B T\sqrt{LC}$$

$$\frac{2LI_c}{\Phi_0} = 1, \quad \frac{2\pi R^2 I_c C}{\Phi_0} \approx 0.7$$

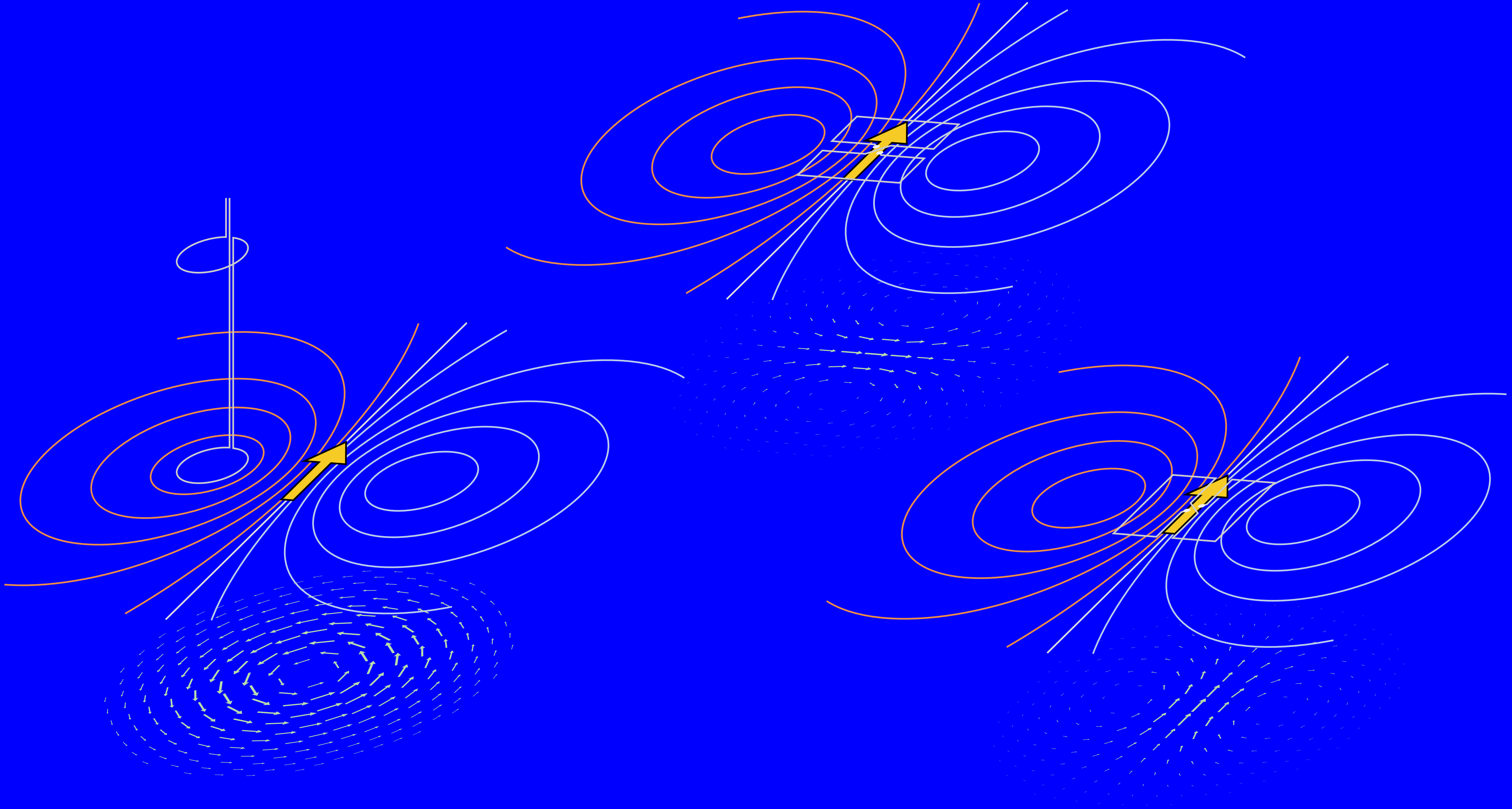


- Small is beautiful
- Signal coupling
- Parasitic effects

Gradiometers



Gradiometers



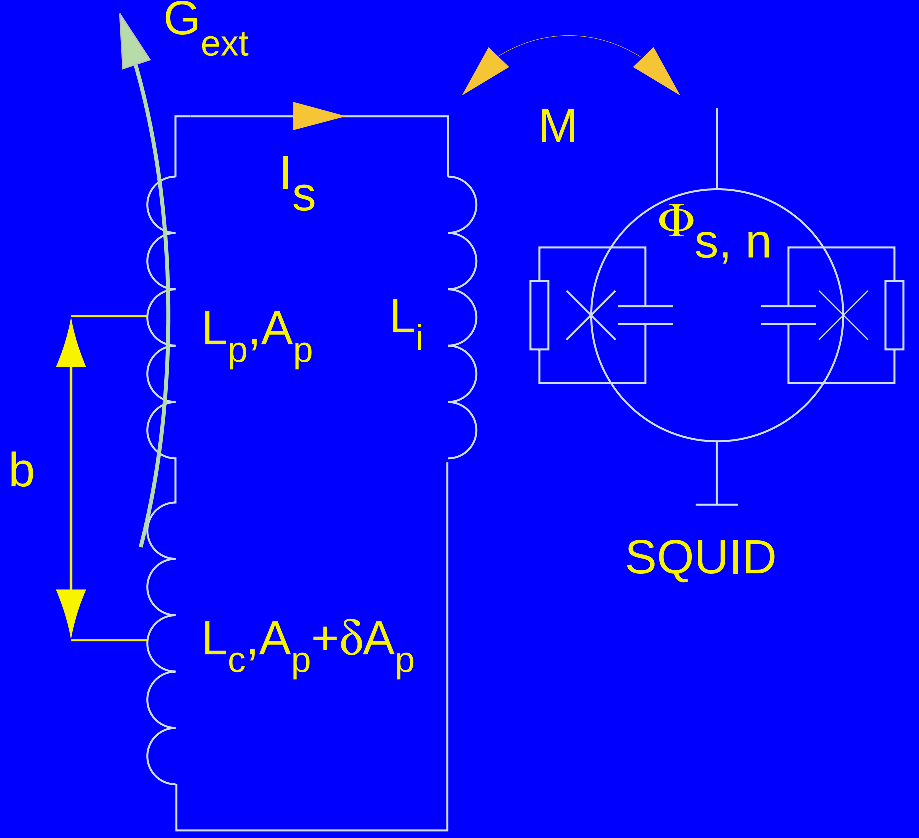
Sensitivity

- Gradient sensitivity

$$G_{\text{ext,n}} = \frac{\Phi_{\text{s,n}}(L_p+L_c+L_i)}{MA_pb}$$

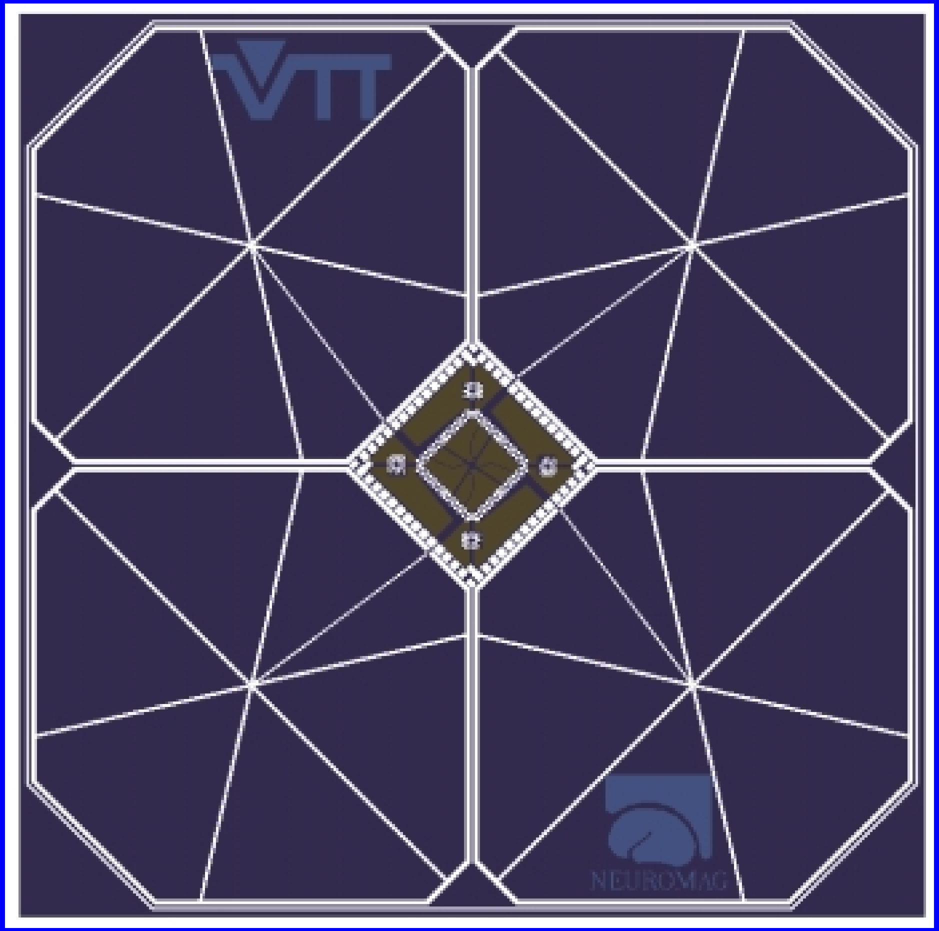
- Interference

$$\Phi_{\text{interf.}} = B_{interf}\delta A_p + A_p b \frac{\partial B_i}{\partial x} + \ldots$$



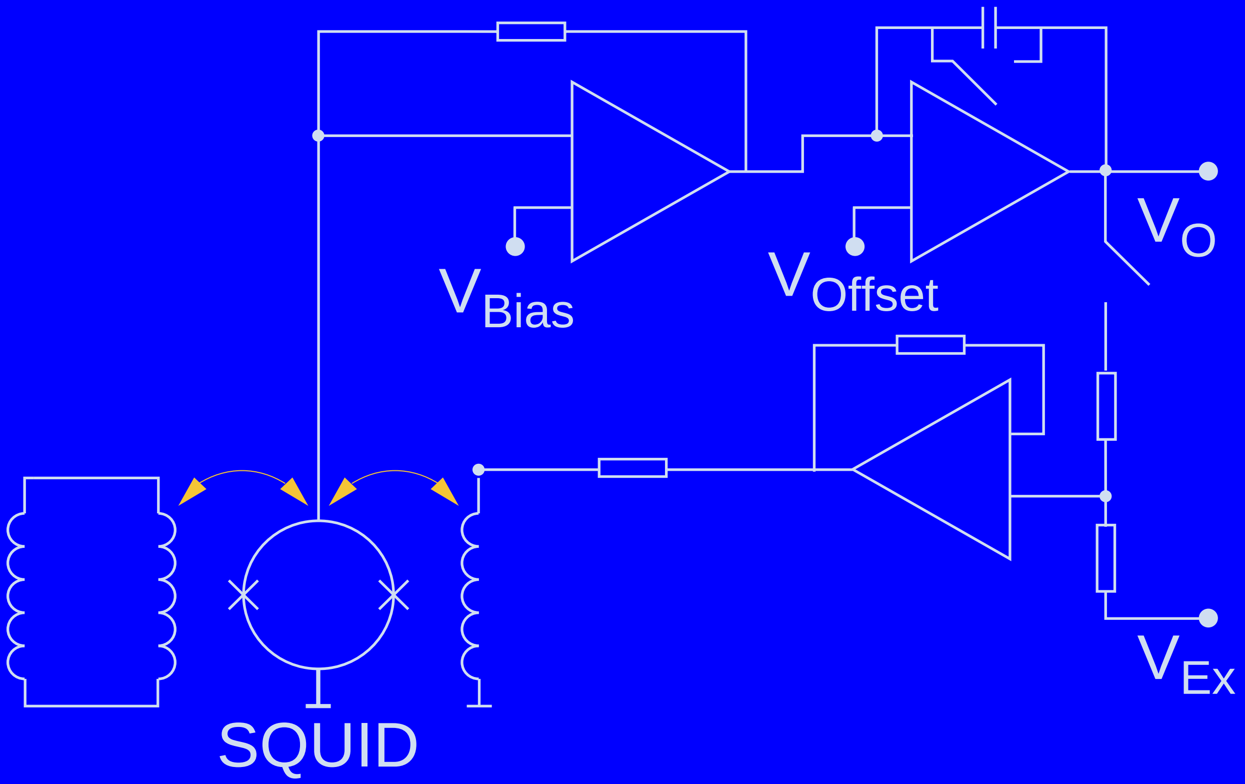
Fabrication

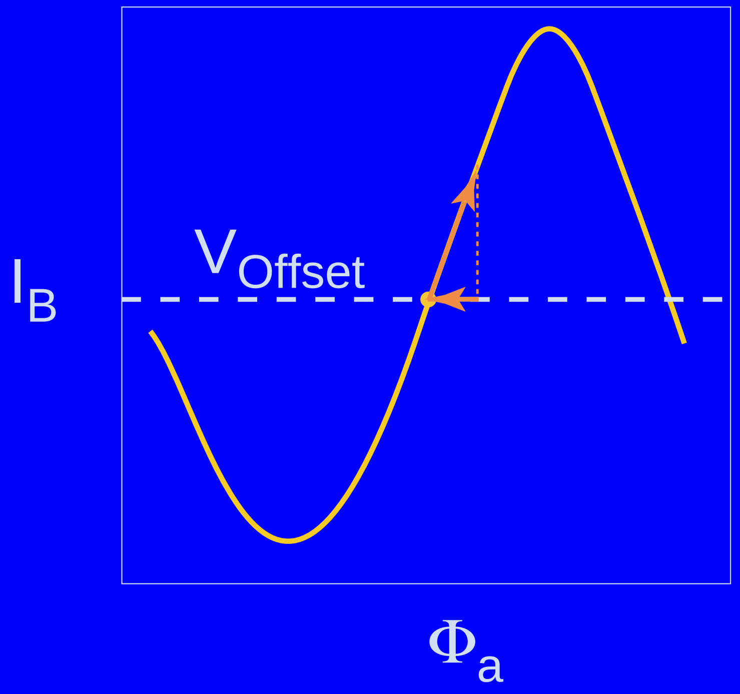
- Thin-film techniques
- Integrated structures



SQUID electronics

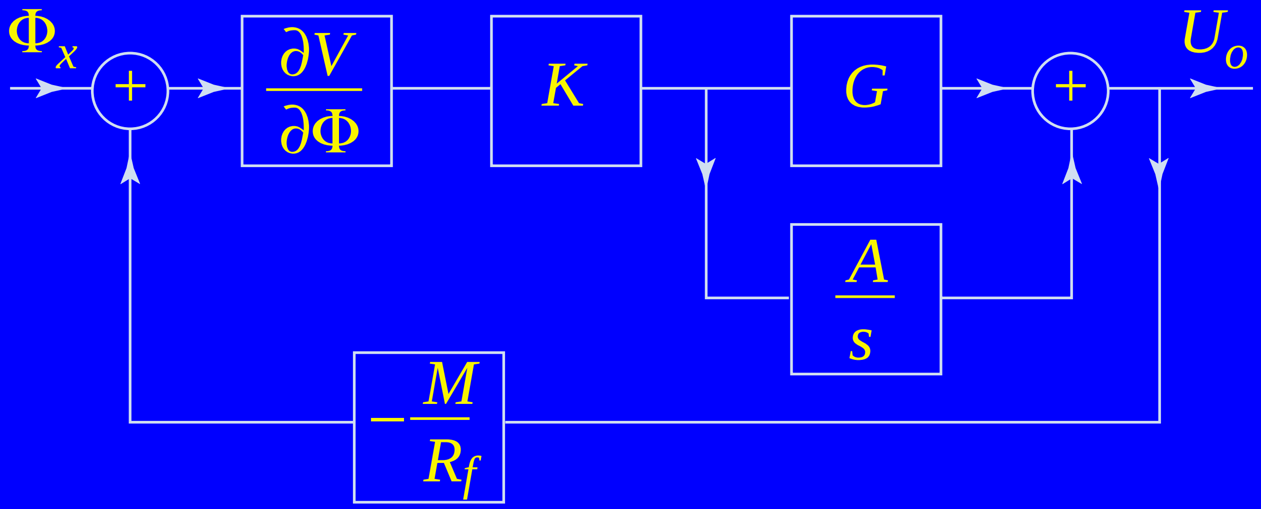
- Flux-locked loop





Flux-locked loop

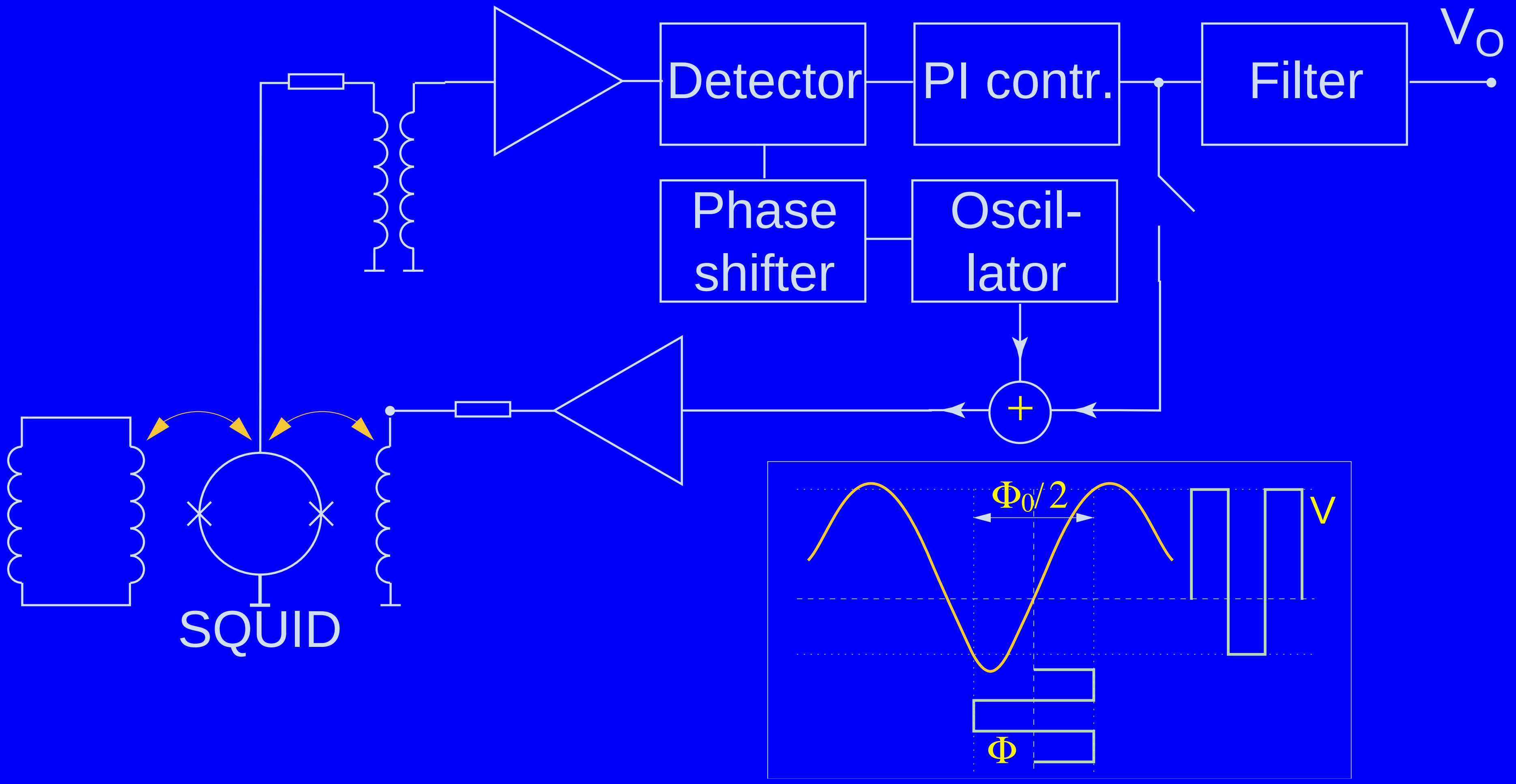
- Proportional-plus-integrating controller (PI)



$$U_0(s) = \frac{\Phi_x}{\dfrac{1}{K\dfrac{\partial V}{\partial \Phi}\left(G + \dfrac{A}{s}\right)} + \dfrac{M}{R_f}}$$

Reduction of amplifier noise

- Flux modulation



Detector

PI contr.

Filter

V_O

Phase shifter

Oscil-lator

+

SQUID

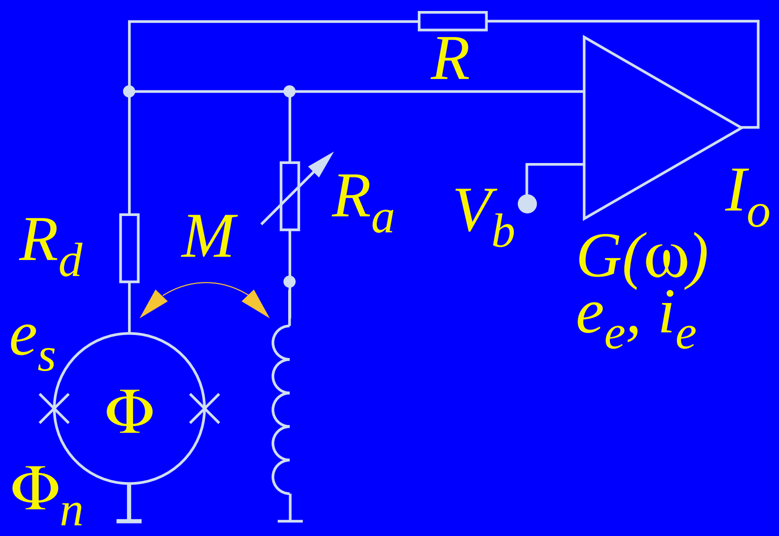
$\Phi_0/2$

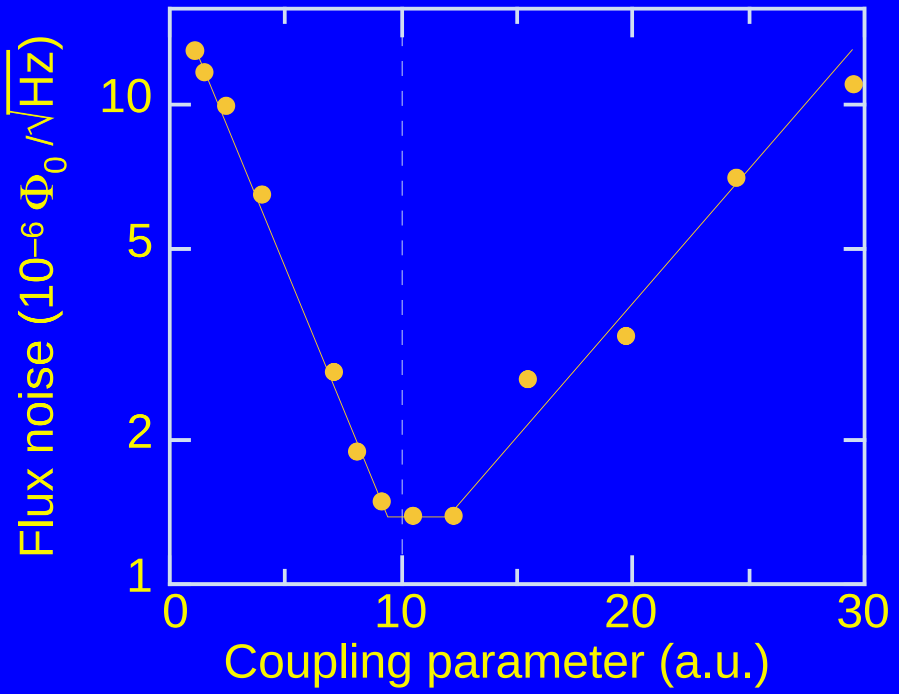
V

Φ

Reduction of amplifier noise

- Amplifier noise cancellation



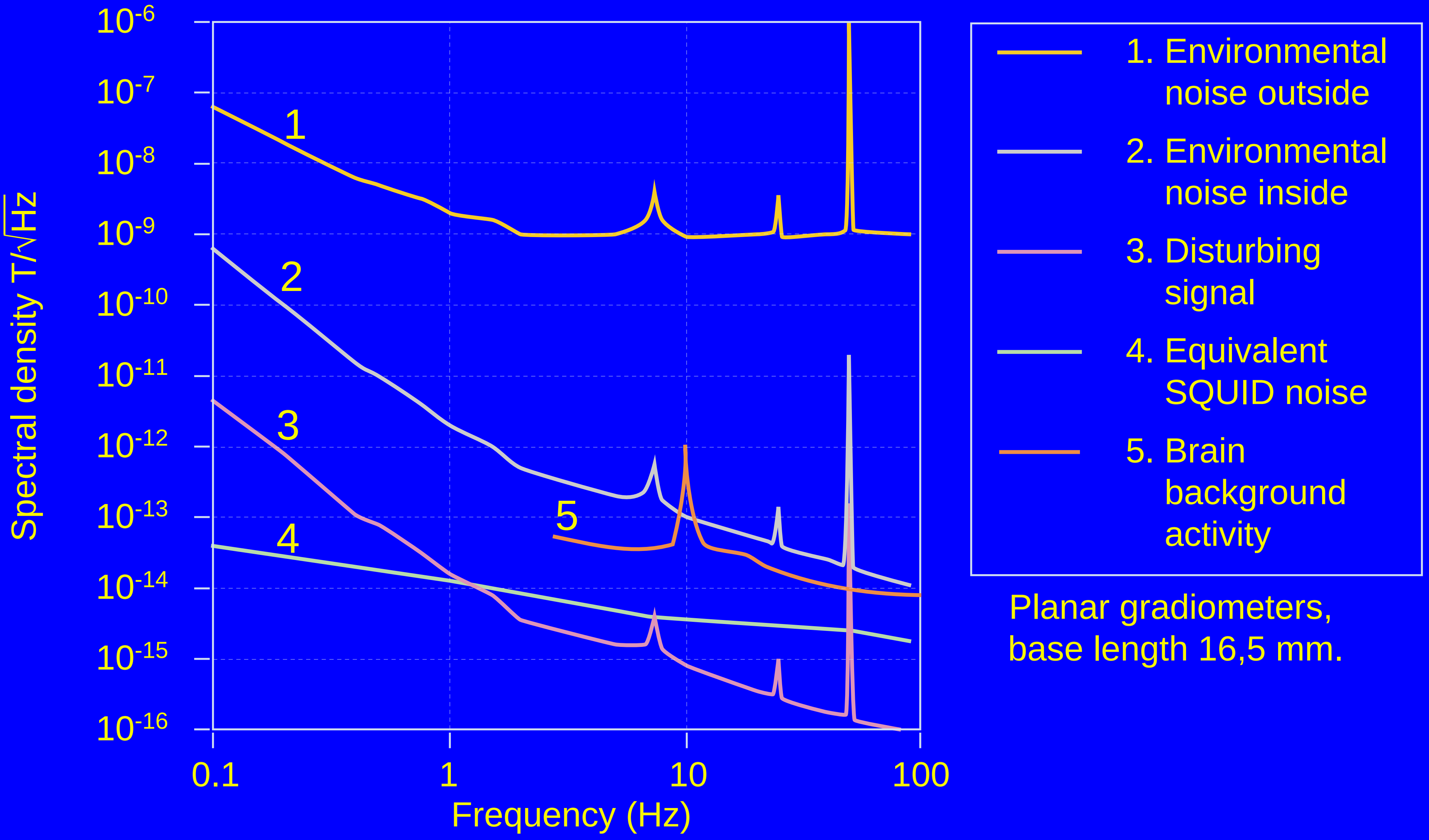


Magnetic shielding and noise reduction techniques

Magnetically shielded rooms

- Mu-metal/Aluminium structure
- Shielding enhanced by active compensation
- Typical performance:
  0.1 Hz –40 dB
  1.0 Hz –60 dB
  10 Hz –80 dB

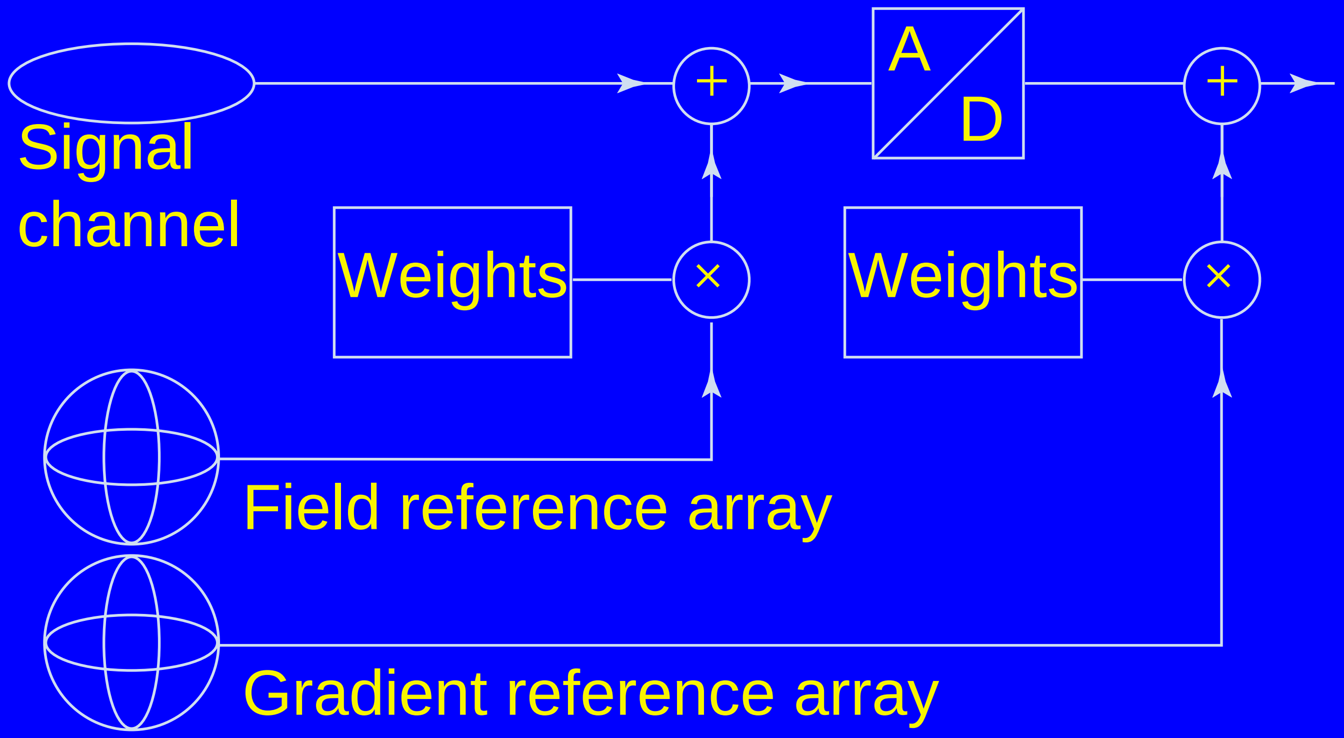
Gradiometers in a shielded room



Planar gradiometers, base length 16,5 mm.

Noise cancellation techniques

- Reference sensors
- Cancellation up to specific order
- “Synthetic gradiometers”



+ A D +

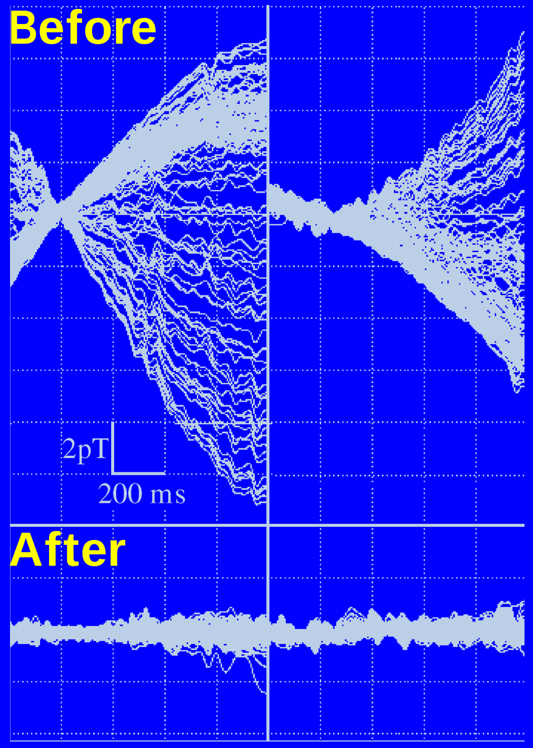
Signal channel

Weights ×

Weights ×

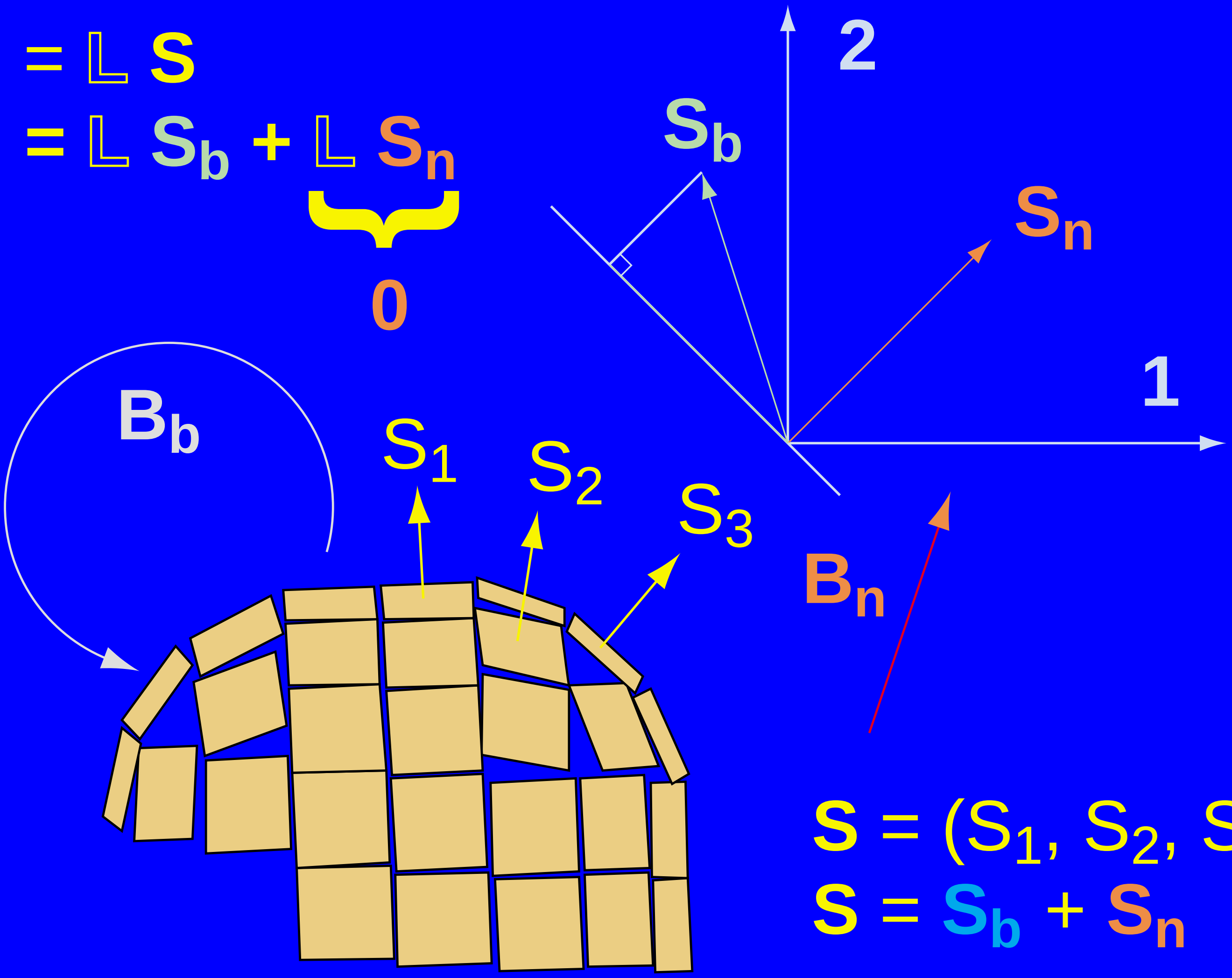
Field reference array

Gradient reference array



Signal space projection

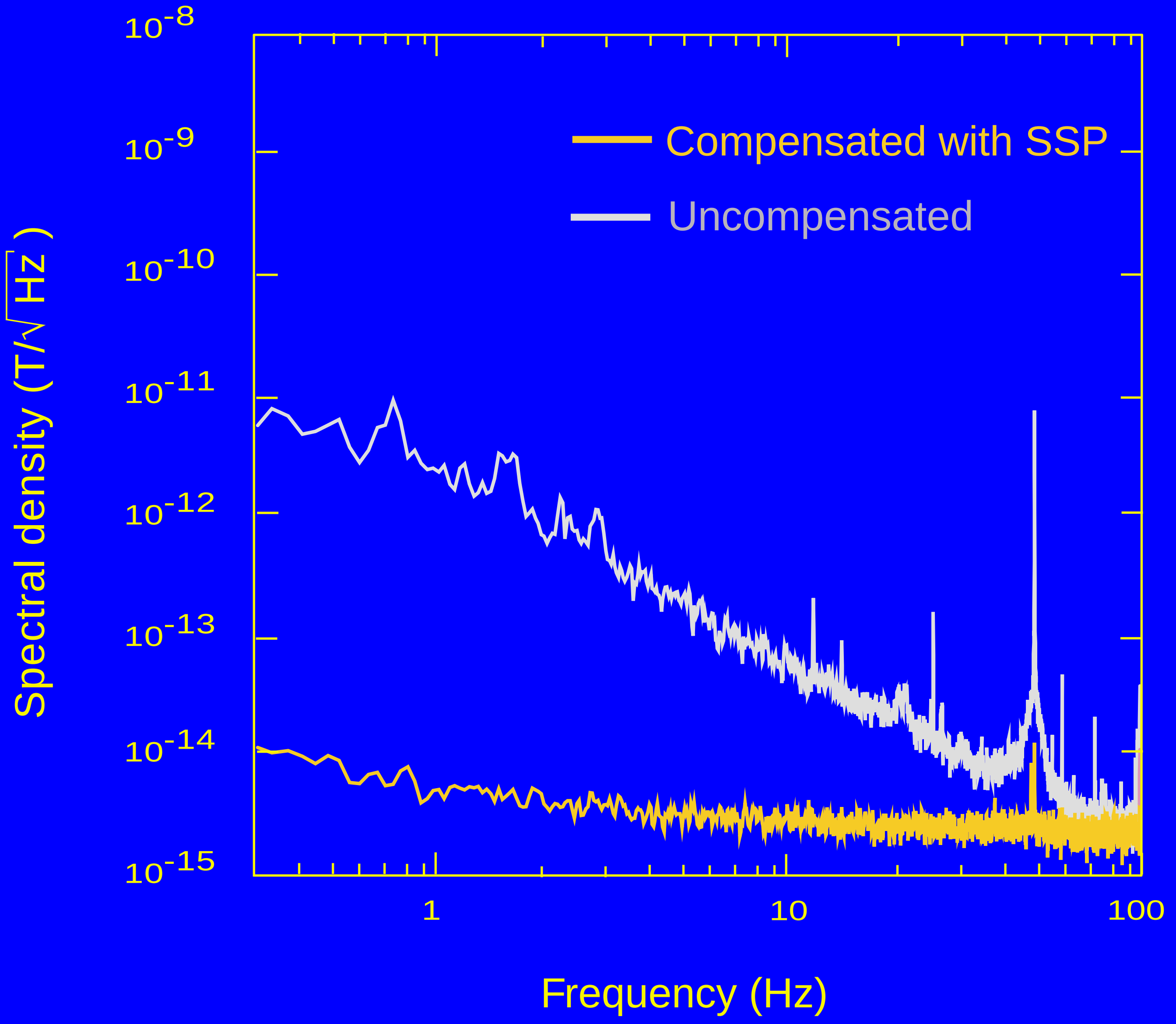
$$
\begin{aligned}
\mathbf{U} &= \mathbb{L}\,\mathbf{S} \\
&= \mathbb{L}\,\mathbf{S}_b + \underbrace{\mathbb{L}\,\mathbf{S}_n}_{0}
\end{aligned}
$$



$\mathbf{S} = (S_1, S_2, S_3, \dots)$

$\mathbf{S} = \mathbf{S}_b + \mathbf{S}_n$

Signal space projection



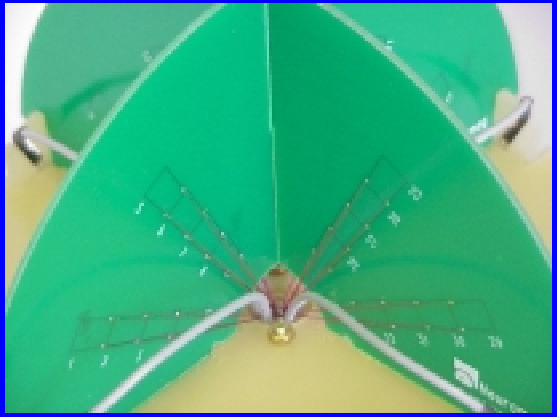
Multichannel systems

Optimization of arrays

- Criteria and results vary
- Spatial sampling theorem
- Information theory
- Localization accuracy
- Detectability

Practical aspects

- Head Position Indicator
  - Alignment with MRI
  - Head shape digitization
  - Relative position
- Phantoms
  - Quality assurance
  - “Wet” and “dry”
  - Calibration
  - Coil arrays



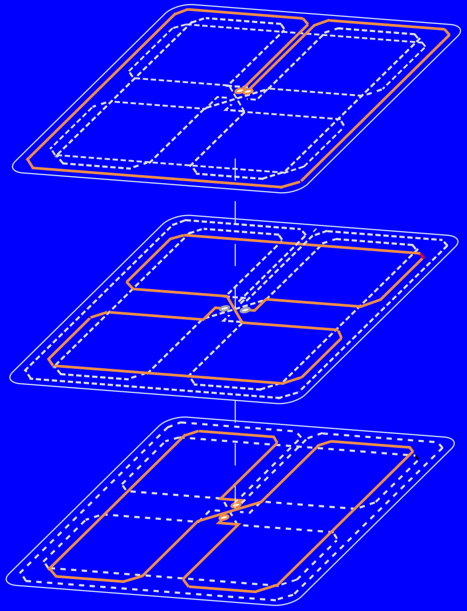
Data acquisition

- Sampling rates up to 10 kHz
- High data throughput
- On-line processing
- Parallel processing

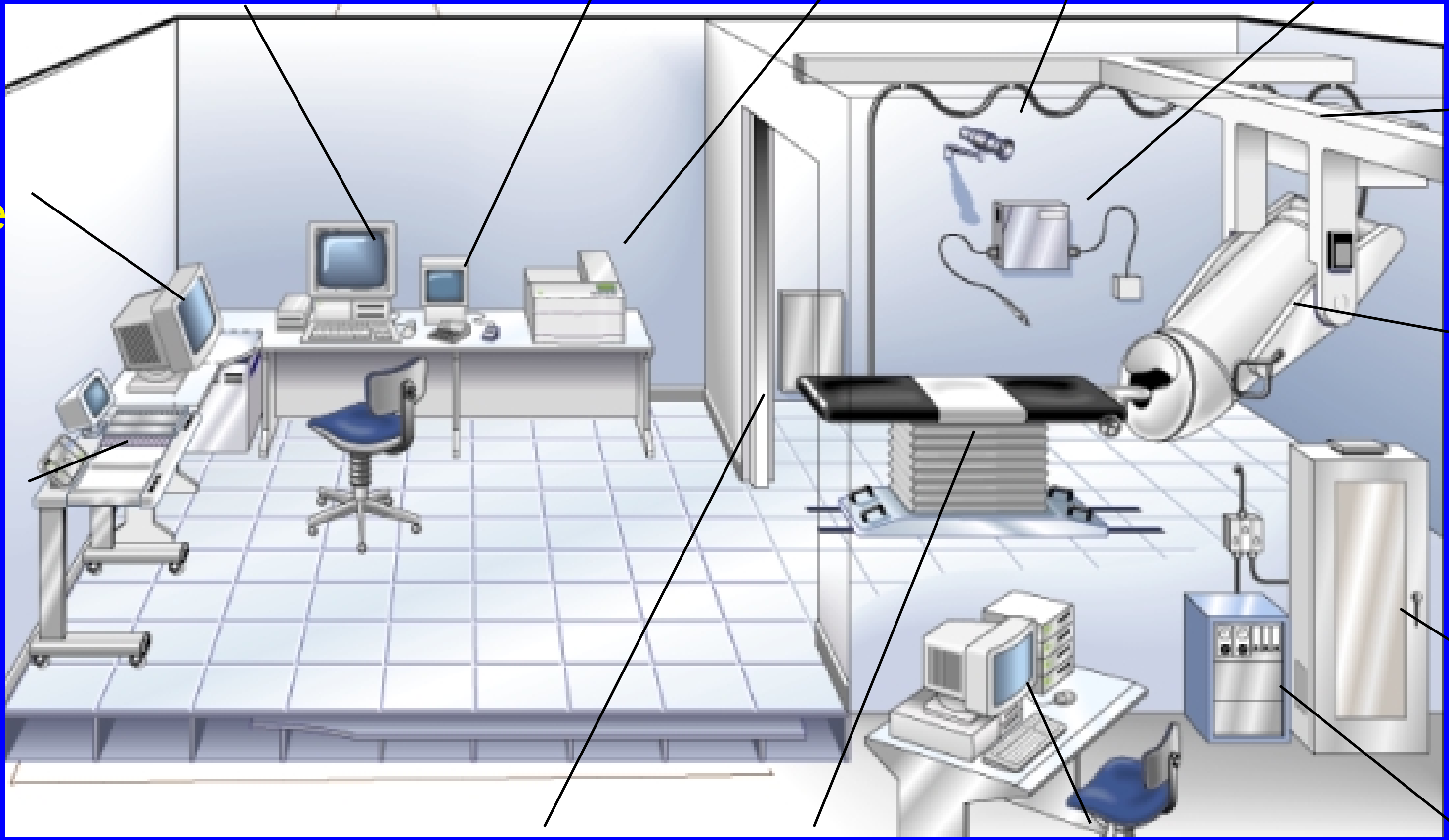
Examples

Example (Vectorview)

- 306 channels
- Triple sensor elements



Layout example (Magnes)



Real Time Display
Video Monitor
Printer
Video Camera
3-D Digitizer

Main Console

EEG

Gantry

Sensor

Electronics rack

MSR

Patient bed

Analysis workstation

Utility rack

Conclusion

- Whole-head coverage
- Sophisticated electronics
- Powerful computer systems
- Work in noisy environments
- Commercial devices
- Method-limited rather than device-limited
- Future ?